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Status Report on the Aerospace Hypersonic Shock Tunnel

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Aerodynamics and Propulsion Research Laboratory

Prepared for COMMANDER SPACE SYSTEMS DIVISION
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LABORATORIES DIVISION • AEROSPACE CORPORATION
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ABSTRACT

The Aerospace Hypersonic Shock Tunnel is described along with an initial calibration at flow Mach numbers of 12, 14, 17, and 18. Room temperature helium is used as the driver gas. Efforts to drive the shock tunnel with combustion heated helium have been made, and these experiments are also described.

CONTENTS

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I. INTRODUCTION

The Aerospace, 66.8 in.-diameter, combustion-driven shock tunnel has been installed; initial calibration and some testing have been accomplished. Contained in this report is a brief description of the shock tunnel, a discussion of the initial calibration with cold helium as the driver gas, including a description of the gauge calibration procedure, and finally an accounting of the efforts to produce controlled combustion in the driver in order to heat the helium driver gas. A more complete description of the shock tunnel, its operation, and final goals is contained in Reference 1.

II. THE SHOCK TUNNEL FACILITY

The shock tunnel consists of three major components: the driver or high-pressure section, the low-pressure or driven section, and the flow nozzle-dump tank. These three segments are depicted in Figures 1, 2, and 3, respectively. The driver and driven sections are separated by a diaphragm, which, when ruptured, permits the establishment of a shock wave that travels down the driven section. The shock compresses and heats the gas behind it. After the shock is reflected from the downstream end of the driven section, the gas is (ideally) brought to rest during a second stage of heating and compressing. It is this now stagnant hot gas behind the reflected shock wave that serves as the supply gas for the blow-down tunnel connected to the end of the shock tube. A thin plastic diaphragm initially separates the driven section from the nozzle, but this is broken when the shock is reflected from the end wall of the tube. Hence, after an initial starting time, flow is established in the nozzle. The flow Mach number depends on the conditions in the driven tube behind the reflected shock and on the ratio of the nozzle test section area to the throat area.

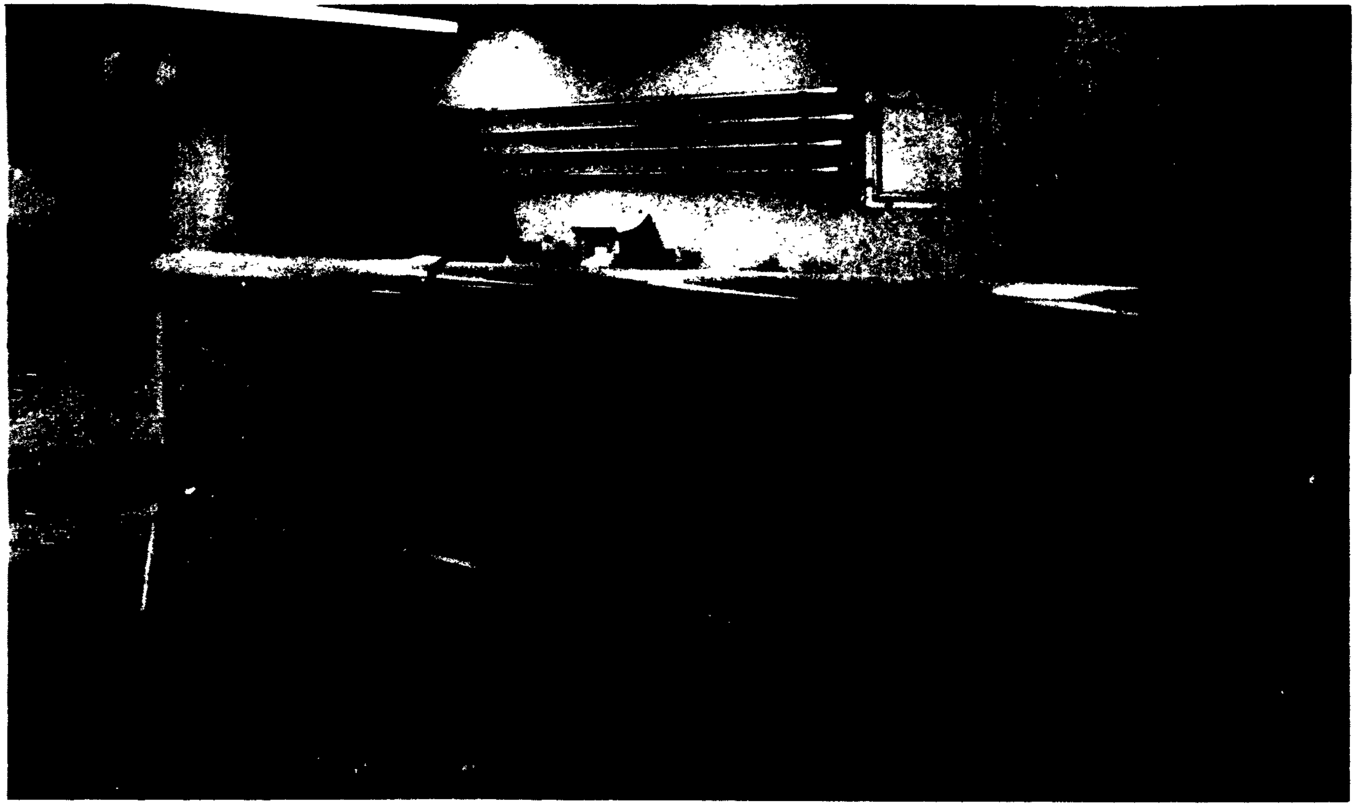


Figure 1. Combustion Driver, Hypersonic Shock Tunnel

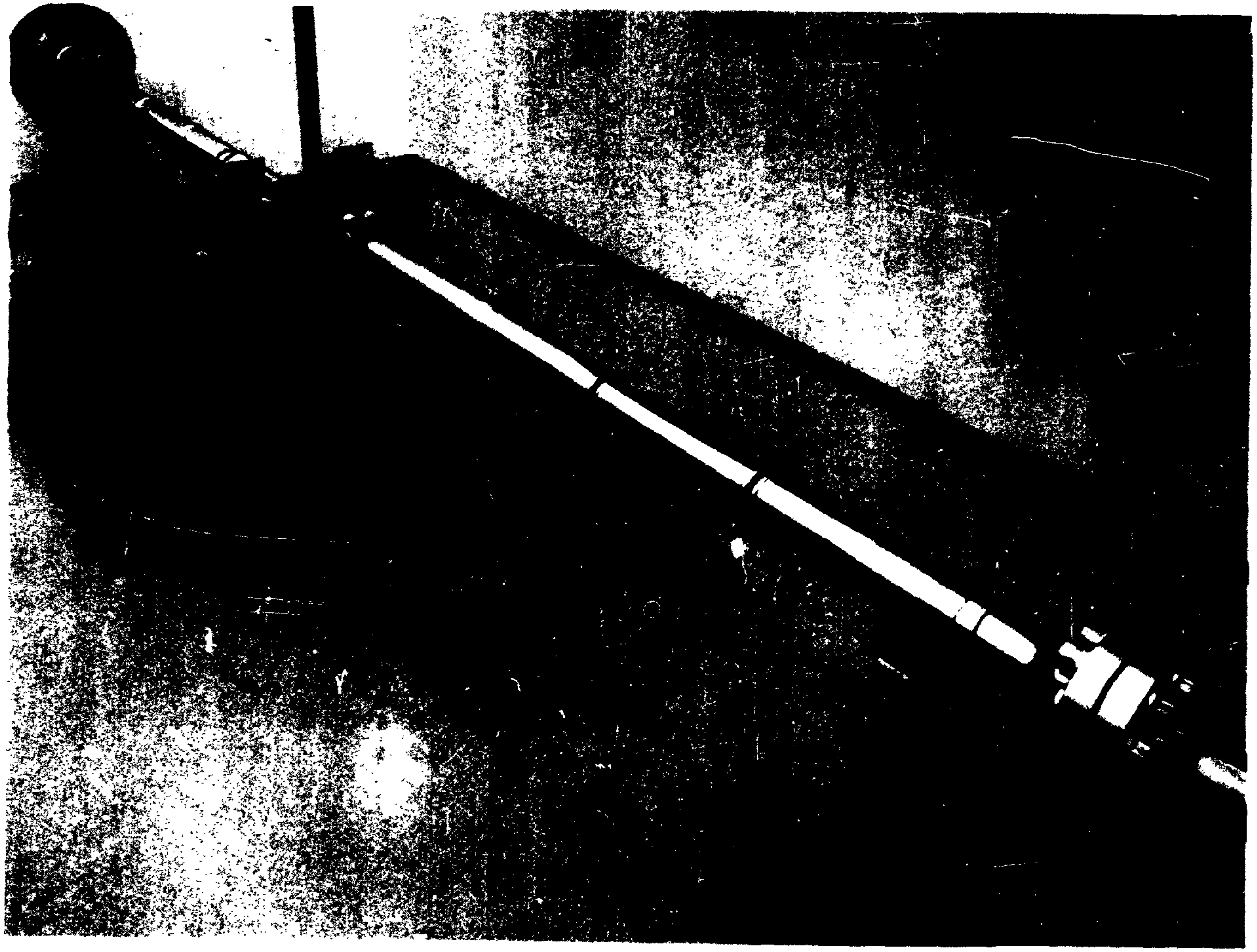
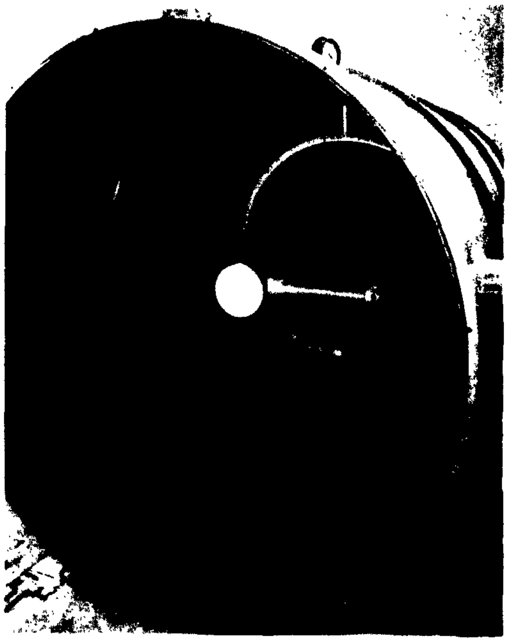


Figure 2. Driver Section, Hypersonic Shock Tunnel

(a) Exterior View



(b) Interior View Showing Nozzle Cone and Model Support

Figure 3. Dump Tank, Hypersonic Shock Tunnel

A tailored (Ref. 2) configuration is employed in the shock tube; that is, the gas in the driver is tailored in such a way that the velocity of sound in the shocked gas in the driven section is the same as that of the expanding driver gas. Hence, the reflected shock wave moving upstream does not interact at the interface between the two gases. As a result, the testing time at the end of the driven section is limited only by the arrival of the rarefaction wave reflected from the upstream end of the driver.

III. TUNNEL CALIBRATION WITH ROOM TEMPERATURE HELIUM

The driver chamber of the shock tunnel is 20.09 ft long with an inside diameter of 3.0 in. The driven section, including the adapter sections at each end, is 34.0 ft long, also with a 3.0-in. inside diameter. Nozzles with throat diameters ranging from 0.040 to 1.0 in. and test sections with diameters of 66.8, 51.8, 35.4, and 22.4 in. provide the tunnel with a wide variety of flow Mach and Reynolds numbers.

Using cold helium as the driver gas, a series of measurements of the tunnel pitot pressure was made for throat diameters of 0.5, 0.75, and 1.0 in. and test section diameters of 66.8 and 51.8 in. During the measurements, the reflected shock pressure at the end of the shock tube was also observed. These two measurements, together with the assumption of chemical equilibrium in the gas in the nozzle, provided the Mach number and Reynolds number of the gas in the test section. Since a pitot rake was employed to measure the total pressure, some estimate of the tunnel flow uniformity and displacement layer could also be obtained.

For about 6000 psi He in the driver, which corresponds to a diaphragm pressure ratio of 400 when the diaphragm bursts, the shock Mach number near the end of the driven section is about 4.3. This corresponds to a reflected shock pressure ratio of 134. Since $M_s = 4.3$ is somewhat beyond

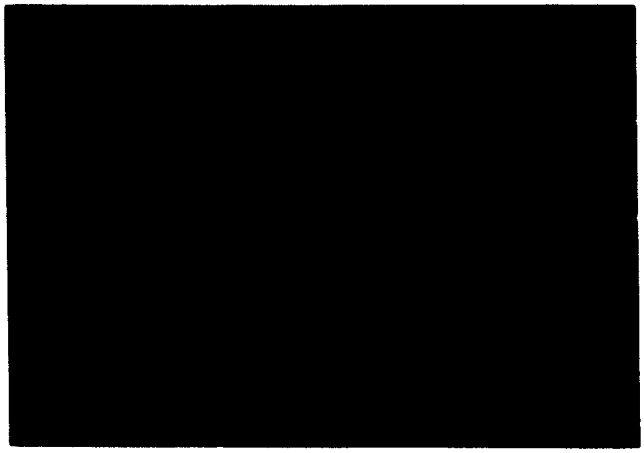


Figure 4. Pressure Behind Reflected Shock Wave at End of Shock Tube

Top record at end wall; bottom record 1.56 ft upstream from end wall. Sweep time 10 msec.

the tailored Mach number, some interaction occurs between the reflected shock wave and the gas interface. As a result, the value of p_5 remains constant only a short time and then rises to new values as waves arrive back at the gauge after the interaction of the shock and the interface (see Refs. 3 and 4). A recording of p_5 as a function of time is shown in Figure 4. From the new pressure value, the temperature can be computed by assuming an isentropic compression from the condition predicted by the shock Mach number to the final pressure measured. Unlike the pressure records obtained in the previous Aerospace shock tunnel (see, for example, Fig. 7, Ref. 5) according to which the pressure became quite steady for about four milliseconds, the records for the present facility indicate that the pressure continues to climb. This is due to the shock wave attenuation accompanying the much longer driven section (136 diameters as opposed to 80 diameters employed previously). The increased testing time of nearly eight milliseconds is also due to the longer driver and driven sections.

The flow Mach number and the Reynolds number for the conditions examined are given in Table 1, and the Mach number profile is shown in Figure 5. As shown in Table 1 and Figure 5, a flow with a Mach number variation of no more than 3.6 percent is obtained over a core 36 in. in diameter for M = 12, 14, and 17. This is large enough to accommodate models 24 in. wide.

Table 1. Mach Number and Reynolds Number Capabilities of Aerospace Cold Helium Driven Shock Tunnel

M	Re/in. (in.$^{-1}$)	A/A*
12.2	18000	1940
14.4	11000	3940
17.1	8250	7740
18.3	5700	15700

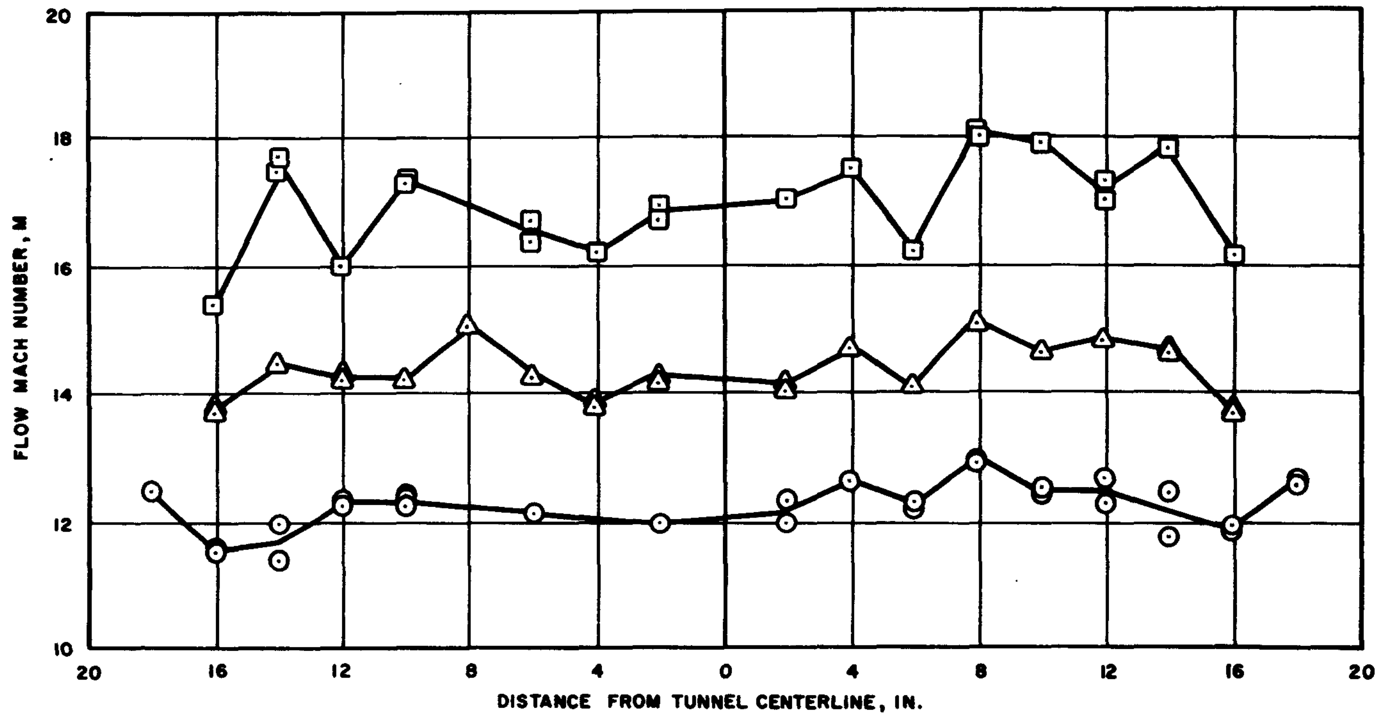


Figure 5. Mach Number Profile

Some comment should now be made about the procedures employed for calibrating the gauges used in the shock tube and in the shock tunnel. In the shock tube, only the gauges measuring the reservoir pressure are calibrated. These are SLM quartz piezoelectric gauges of such construction and insulation as to permit static preliminary calibration using an Ashcroft, 0-5000 psi dead-weight tester. For dynamic calibration, the gauge is inserted in the shock tube, and, with the throat blocked off, the gauge response is observed during a firing. The value of the output of the gauge as a function of the pressure determined from the measured shock Mach number is recorded and compared with the value obtained from the dead-weight tester. These results are shown in Figure 6. Since the gauge is used to make a dynamic measurement, it was concluded that only the dynamic calibration results should be used in determining pressure and temperature in the shock tunnel.

Barium titanate and lead zirconate ceramic element gauges manufactured by the Atlantic Research Corporation after a design developed at the Ballistic Research Laboratory (Ref. 6) are used in recording the pitot pressure in the tunnel test section. These gauges are calibrated at pressures ranging from 2 to 800 mm absolute in a calibration shock tube. In addition, a calibration is accomplished using a modified dynamic loudspeaker driver manufactured by Photocon Research Products. This driver can develop high pressures in a small cavity with reasonably smooth frequency response characteristics up to about 4000 cps. With the gauge to be calibrated coupled to the driver by a small cavity, rms pressures of up to 1/20 atm (164 dB above 0.0002 dynes/cm^2) can be developed on the pressure gauge. The dynamic loudspeaker is calibrated using a Bruel and Kjaer microphone as a standard. Electrical power requirements for the system are small. The results of the two methods of calibration agreed within the accuracy of the measurements. Since the dynamic loudspeaker driver method seemed to be the easiest and quickest, it was decided to use this method generally and make occasional checks on the calibration shock tube.

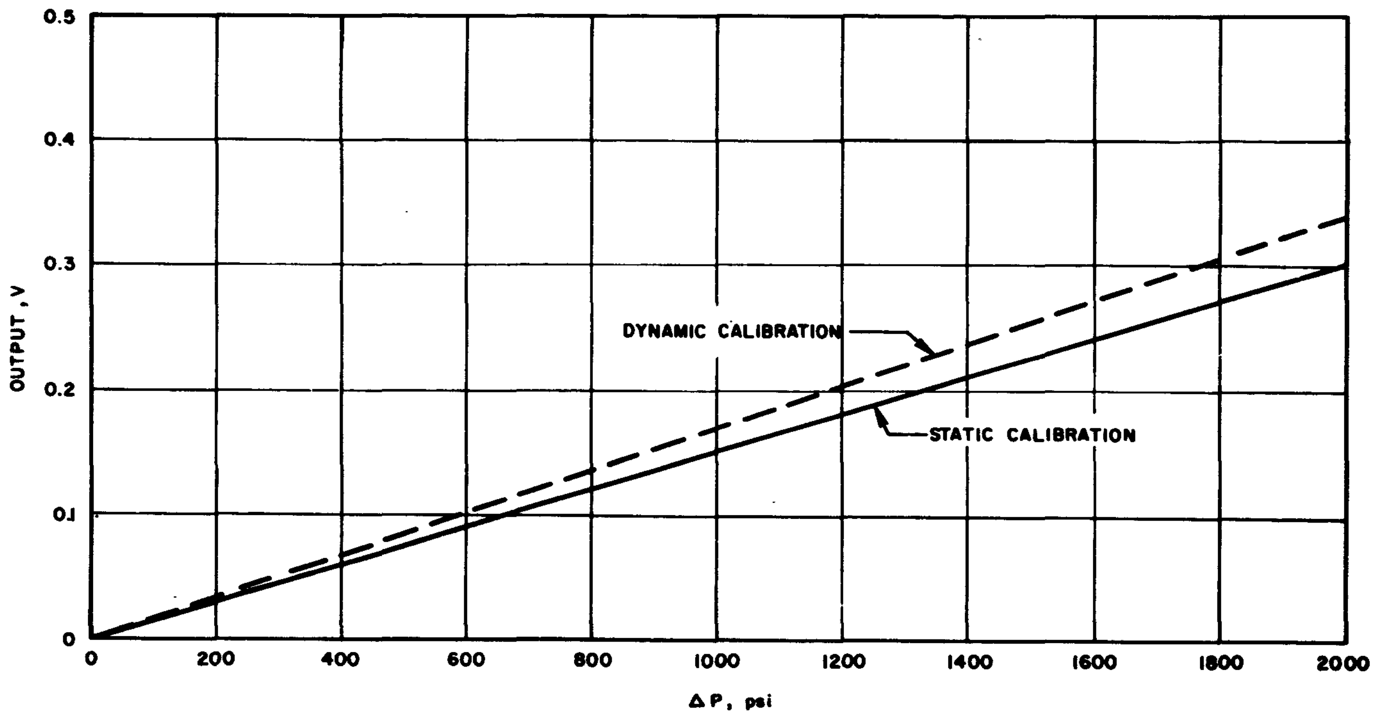


Figure 6. Comparison of Static and Dynamic Calibration of SLM Quartz Pressure Transducers

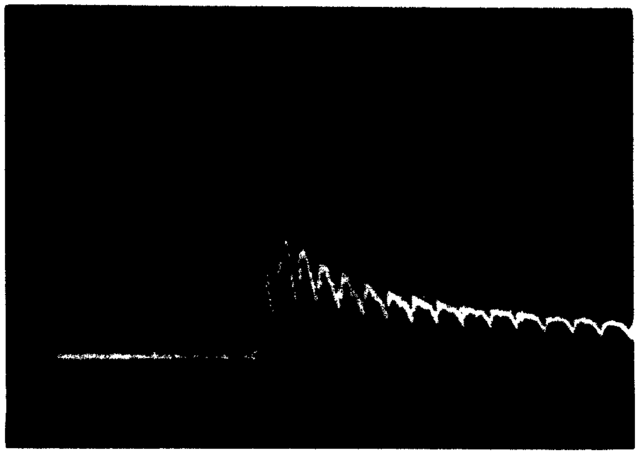
After the pitot pressure gauge is calibrated, it is installed in a model and thus is remote from the amplifying and recording system. Because of variations in the gain of the system, measurement of the voltage signal generated by the transducer is difficult. One method of determining the system gain is to insert a small known voltage from an external generator in series with the transducer and to observe the resulting output at the recording system. Thus, the gain of the system including all the cables is determined. The gauge-generated signal can then be computed from the known gain of the system and, with the calibration data for the gauge, the pressure determined.

IV. COMBUSTION DRIVER EXPERIMENTS

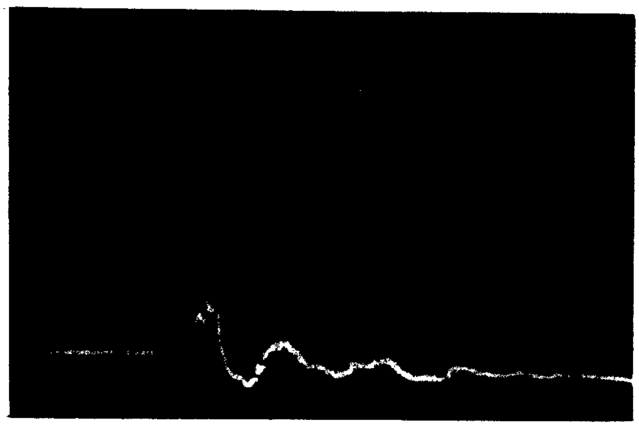
The combustion driver chamber is designed for a working pressure of 30,000 psi with an ultimate strength of 165,000 psi. At initial charge pressure of 4000 psi of stoichiometric hydrogen and oxygen with 75 to 80 percent helium diluent, the pressure after combustion is expected to be in the neighborhood of 30,000 psi. It is possible that, in the event of detonation, the pressure will match the ultimate strength of 165,000 psi.

A fill tube of 1/2-in. diameter is connected to the gas inlet line at the upstream end of the driver and extends the length of the driver. Along the length of the fill tube are openings increasing exponentially in size with the distance from the gas inlet point. In this way, the gas is expected to flow into the driver uniformly along its length.

It was planned to use a glow wire technique employed by Convair (Ref. 7) to initiate the reaction in the combustion experiments. According to this technique, a glow wire is stretched along the axis of the tube and, using ordinary utility-service power, is slowly heated to the initiation temperature of the gas mixture. In our system, we used a palladium-clad aluminum wire



(a) Constant Volume Test



(b) Detonation Occurring During Constant Volume Test, Shattering Diaphragms

Figure 7. Combustion Driver Tests

(pyrofuse wire), which alloys exothermally when heated to the alloying temperature and produces a self-sustaining reaction. A Norwood strain-type pressure gauge rated at 60, 000 psi is used to measure driver gas pressure during the reaction.

To date, some 25 firings have been made with the driver section either blocked off or left open to the driven section. In addition, some tests were made that were intended as closed-driver (i. e., constant-volume) tests but that became open tests when the blocking diaphragms were shattered by a strong detonation. Attempts to produce a smooth combustion of the diluted hydrogen-oxygen mixture met with varying degrees of success. The best example of these efforts was a closed-volume test, the results of which are shown in Figure 7a. The concentrations of O_2, H_2, and He used in this test were 9. 6 percent, 15. 8 percent, and 74. 6 percent, respectively. (This mixture actually had excess oxygen.) According to the pressure record, the pressure reached ~6000 psi. When this test was repeated, however, the diaphragms shattered as a result of the detonation pressure,as indicated in the record of Figure 7b. In addition, there was a negative phase in the pressure record that represented a pressure much below absolute zero.

Current and voltage records of the power delivered to the wire combined with the pressure record indicate that, for a loading pressure of 1000 psi, there is a delay of from 10 to 20 msec before the reaction is initiated. When the loading pressure is 600 psi, the delay is about 60 to 80 msec.

The suspicion that the slowly heated wire could initially have a non-uniform temperature distribution was confirmed by high-speed movies of the wire heated in air. It was noted that the wire almost invariably became luminous at a single point, and that it took from 10 to 20 msec before a more or less uniform distribution of hot spots appeared along the wire. This simply means that, if initiation occurred at one point because the wire heated there first, then the wave originating at that point could reach the gas in any other part of the driver before the wire there had reached ignition temperature.

Hence, the reaction in the gas could attain detonation before any other reactions were initiated. However, the reason for using the wire was to ignite the gas at a large number of points simultaneously so that no unreacted gas path would exist in which a detonation wave might develop.

Series of short lengths of pyrofuse wire spaced either 4 ft or 2 ft apart and connected by lengths of No. 12 wire were made to ignite simultaneously in less than 300 μsec, the resolution of our high-speed camera. It was decided to use series like these to touch off the reaction at as many points as seemed necessary. Initial attempts with an arrangement of 5 short lengths 4 ft apart and 2 ft from each end, and then attempts with lengths 2 ft apart and 2 ft from the ends, produced the same results as did the long strand of wire.

At present, the plan is to use a capacitor discharge to initiate a wire made of tungsten rather than pyrofuse. The assumption is that the capacitor discharge circuit will dump the energy into the wire so fast that there will not be time enough for the non-uniform spots to heat in an appreciably different manner from the rest of the wire. The reacting pyrofuse is to be eliminated because it introduces an additional perturbation (the wire reaction itself travels along its length), the effects of which are not known.

Some suspicion has been cast upon the behavior of the pressure gauges used to measure the driver reacting gas pressure. Particularly suspect is the negative phase of the record. The gauges are being re-calibrated, and, in addition, will be used to measure a gas reaction in a small chamber where the gas mixture can be very carefully controlled and where, because of the size of the chamber, a combustion reaction can be produced. The negative response of the gauge may be due to thermal loading. A shield against both conductive and radiative heat transfer is to be provided for the gauge. After these changes and tests have been accomplished, it is hoped that an improved combustion reaction can be produced in the driver of the shock tunnel.

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